

Effect of Inconsistencies in Precipitation Data on a Conceptual Hydrologic Model

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Introduction

Within the National Weather Service (NWS) long periods of historical data are used when calibrating and applying conceptual models for river forecasting. During calibration, typically 10 or more years of data are used to determine proper values for model parameters and then additional periods of record are utilized to verify the results. When producing extended probabilistic predictions of streamflow or other hydrologic variables, as many years as possible of historical data are used to generate possible ensembles of what might happen in the future. One question that arises when analyzing historical data to produce model input is how important is it to check and correct for inconsistencies in the data. This report looks at the effect of inconsistencies in precipitation data on simulation results.

Background

Inconsistencies in precipitation gage records can occur when there is a physical change at a station. The most common situation is when the equipment is moved to a new location. Other possible causes are equipment changes (e.g. gage replaced by a different type or a shield added or removed), alterations to how a gage is installed, or physical changes at the site affecting exposure. Some climatological networks in the United States are very stable, i.e. there are seldom changes to equipment or site locations. One example of such a network that is utilized extensively by the NWS for hydrologic applications is the SNOTEL network maintained by the Natural Resource Conservation Service (NRCS). Stable networks tend to be adequately funded, automated, and maintained directly by a governmental agency. However, the main climatological network that is used as a source of data for historical analyses by the NWS exhibits periodic changes that could result in station data records that are inconsistent over time. This is national climatic data network maintained by the National Climatic Data Center (NCDC). This network relies on cooperative observers which can be private citizens or personnel working for a private company or government agency. This results in periodic changes in observers which can require moving a gage from one location to another. Also since the NCDC network has been in existence for so long, equipment or exposure changes occur sometime during the period of record at many sites.

The primary technique used for checking the inconsistency of precipitation data has been a double mass analysis. In this technique the accumulation at a given station is plotted against the average accumulation for a group of stations. When the number of stations in the group is reasonably large, the accumulation of the group average should be quite stable. Thus, if there is a change in the relationship between a single station and the group at some point in time, it is likely that there has been a change in the precipitation measured at that station. This deviation can be removed by multiplying a portion of the record at that station by a factor that will produce a generally straight line relationship. In the NWS River Forecast System (NWSRFS), in order to more easily be able to see slope changes when working with very long records, the double mass

plots display the accumulated deviation of a single station from the group average plotted against the accumulation of the group average.

The primary difficulty when checking the consistency of precipitation data is determining when deviations from a straight line relationship are caused by natural spatial variability in precipitation and when they are produced by physical changes at the station. While much of the natural spatial variability in precipitation produces random fluctuations that don't persist for an extended period, there are natural variations in the records over a given region that can remain for many years due to changes in the prevalent storm tracks or storm types. In order to only adjust for real inconsistencies caused by physical changes at a station, the following guidelines have been recommended:

1. Generally only make consistency corrections when there is a documented physical change at a station that could produce an inconsistency. The only exception is when the change in the double mass plot is very large and can't be explained by natural variability.
2. The inconsistency should typically persist for a number of years (generally for the remainder of the record or until the next physical change takes place at the station).
3. Multiple stations should be displayed on each plot and the stations should be grouped for plotting by location (may include elevation and orographic exposure) to assist in identifying natural variations. When multiple stations in a given area exhibit a change in slope at the same point in time, it is most likely caused by changes in the prevailing storm type or track.

One of the problems with the NCDC climate network is that there is no absolute documentation of all the physical changes that have occurred at each station. Cooperative Program Managers (CPM's) attempt to keep complete documentation, but given the number of stations and the frequency of site visits, it is a most difficult task. Also various sources of station history information maintained by NCDC frequently don't agree as to when physical changes occurred. In addition, there seems to be no set rules for determining when a station move should result in the establishment of a new station. In some cases the equipment is moved only a short distance with little elevation change and a new station is established while in other cases the equipment is moved many miles away with no change in the station other than the name being modified (i.e. still archived as the same station though the name may, for example, change from ANYTOWN 3 NW to ANYTOWN 5 SSE).

All of this creates a dilemma as to when to make consistency corrections and the effect of such corrections on the calibration of models and use of the historical data for other applications such as input for extended probabilistic predictions. Some people advocate not making any consistency corrections to the historical data based on the assumption that the natural spatial variability of the data will be altered. Most hydrologists realize that there are legitimate reasons for making such corrections and thus, if done carefully, adjustments should be made to the historical data to remove obvious inconsistencies. Of course, if corrections are over applied to obtain an unrealistically straight line double mass plot, the result will likely negatively affect the data applications. This report uses actual historical data to illustrate some of the difficulties in determining consistency corrections and the effect of inconsistencies in precipitation records on the simulation results from a conceptual hydrologic model.

Throughout this study the procedures and recommendations described in the manual “Calibration of Conceptual Hydrologic Models for Use in River Forecasting” dated August 2002 by this author were followed. Thus, if someone wants more detail on any of the procedures, they are referred to that Calibration Manual (copies can be obtained via the Internet at <http://www.nws.noaa.gov/oh/hrl/calb/calbmain.htm>).

Case Study

Study Area

In order to look into the effect of precipitation inconsistencies on model calibration and simulation results the following were needed:

1. An area with one or more stations that clearly had inconsistencies during their periods of record (wanted to work with real data, not generated data),
2. A headwater drainage with few if any complications, a long streamflow record, and inconsistent precipitation stations that have a significant weight when calculating areal precipitation estimates, and
3. An area that generates considerable runoff, has a good precipitation gage network, has a minimal amount of spatial variation in rainfall during storm events, and where snow has a minimal effect – all needed so that reliable areal precipitation estimates can be generated and model calibration should be fairly straightforward.

With the help of the Northwest River Forecast Center (NWRFC) an area was found in the central Cascades of Oregon that met these criteria in a reasonable fashion. The drainage area is on the Row River above Dorena Dam just east of Cottage Grove, Oregon. The streamflow record used is for the Row River above Pitcher Creek near Dorena (USGS gage number 14154500). The drainage area for this headwater area is 211 sq. mi. with elevations varying from 856 to 5960 feet. Snow does occur periodically in this watershed though only the highest elevations maintain a sizeable snow cover throughout much of the winter during most years. The 1950 through 1999 water year period of record was selected for the study. The watershed has nearly 60 inches of precipitation per year (ranging from just below 50 inches at the lower elevations to 75-80 inches at the highest elevations). The mean annual runoff is nearly 40 inches. Most of the storms have a significant orographic component. The intercorrelation of monthly totals between all the precipitation gages used was over 0.92.

The main point of interest to the NWRFC is the inflow to Dorena Dam which is located downstream from the USGS gage (drainage area is 266 sq. mi.). The NWRFC generated streamflow data for the Dorena Dam inflow site by multiplying the USGS gage by a factor (1.228) that accounted for the differences in drainage areas and average precipitation.

Precipitation Data and Consistency Analysis

A total of 20 precipitation gages representing 16 sites were used for this study (4 sites had both recording and non-recording gages). Table 1 lists the stations used and some information about the record for each. Figure 1 shows the location of the stations relative to the watersheds.

Station Name	Sta. #	Interval	Latitude	Longitude	Elevation (ft)	Period of Record
Dorena Dam	35-2374	Hourly	43.78	122.97	820.	2/50 – 9/99
Dorena Dam	35-2374	Daily	43.78	122.97	820.	10/49 – 9/99
Disston 1 NE Laying Creek	35-2345	Hourly	43.70	122.73	1218.	10/49 – 9/99
Disston 1 NE Laying Creek	35-2345	Daily	43.70	122.73	1218.	10/49 – 12/76
Cottage Grove Dam	35-1902	Hourly	43.72	123.05	831.	10/49 – 9/99
Cottage Grove Dam	35-1902	Daily	43.72	123.05	831.	10/49 – 9/99
Cottage Grove 1 NNE	35-1897	Daily	43.80	123.05	595.	10/49 – 9/99
Blackbutte 1 N	35-0781	Hourly	43.60	123.07	970.	10/49 – 9/99
Hills Creek Dam	35-3915	Hourly	43.72	122.43	1247.	11/60 – 9/99
Lowell + Lookout Point Dam	35-5050	Hourly	43.92	122.77	712.	2/50 – 9/97
Lookout Point Dam	35-5050	Daily	43.92	122.77	712.	9/55 – 9/99
Sutherlin 12 NNE	35-8263	Hourly	43.43	123.08	960.	3/55 – 8/99
London 1 N	35-5008	Daily	43.65	123.08	932.	10/49 – 9/67
Upper Steamboat Creek	35-8790	Hourly	43.48	122.60	1855.	12/56 – 9/99
Steamboat Ranger Station	35-8102	Hourly	43.35	122.73	1200.	3/55 – 9/99
Lemolo Lake 3 NNW	35-4835	Daily	43.37	122.22	4077.	10/78 – 9/99
Oakridge Fish Hatchery	35-6213	Daily	43.75	122.45	1275.	10/49 – 9/99
Holland Meadows Snotel	22F42S	Daily	43.66	122.56	4900.	10/80 – 9/99
Toketee Falls	35-8536	Daily	43.28	122.45	2060.	2/53 – 9/99
Odell Lake Land Pan	35-6251	Daily	43.58	122.05	4793.	10/49 – 9/72

Table 1 – Precipitation stations used for the study.

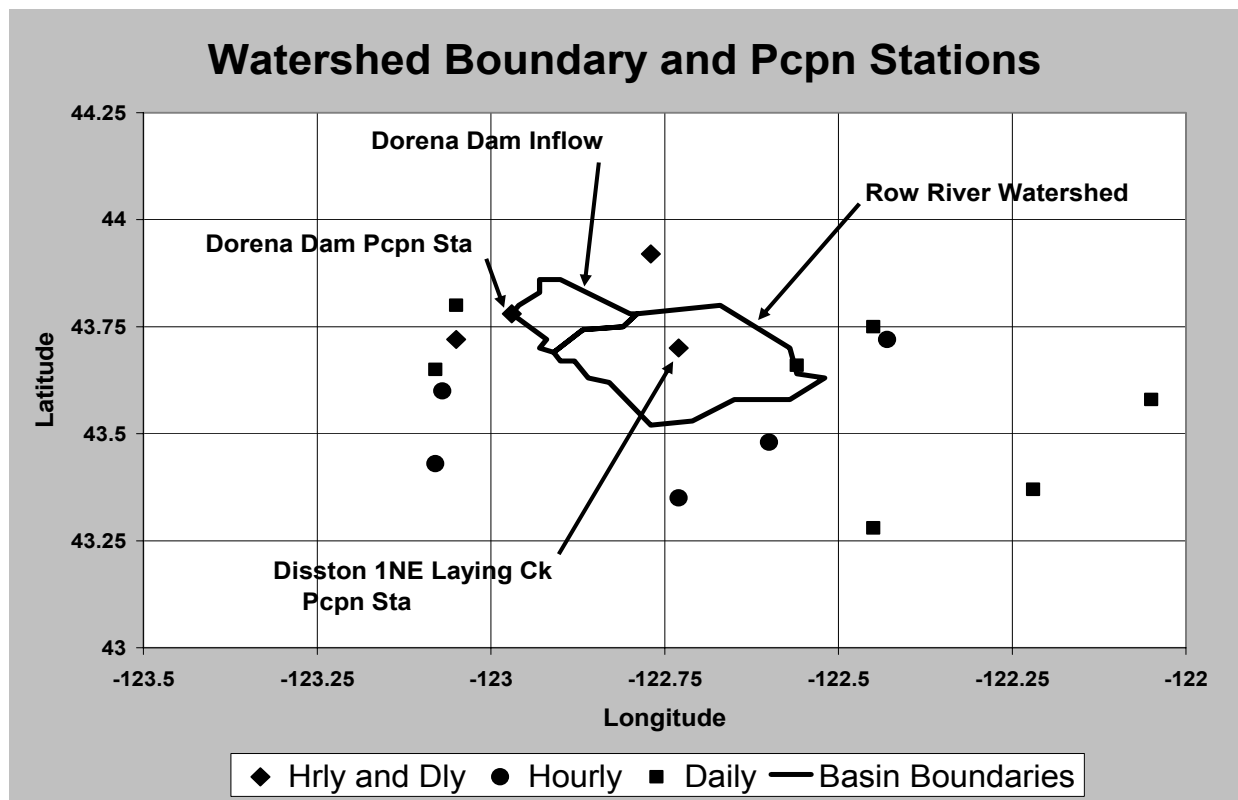


Figure 1. Location of precipitation stations relative to the Row River watershed.

The consistency of the precipitation data were checked using the NWSRFS preliminary processing program for precipitation (referred to as PXPP). The PXPP program estimates mean monthly precipitation for the period of record in a consistent manner. The approach uses the average monthly ratio of the precipitation for each station to a base station. The ratio is computed only for those months when both stations have complete data. The base station should have a naturally consistent record and very little missing data during the period being used. PXPP uses the ratio to base values to estimate totals for each month with missing data to complete the record for all stations. Missing values are estimated from surrounding stations using a $1/d^2$ procedure. The ratio to base for each of the surrounding stations divided by the ratio to base for the station being estimated is used to adjust the data prior to estimating missing values. Once the record is complete for all stations, double mass plots can be generated to check the consistency of the precipitation data. Periods with missing data and times when station moves or other changes have been documented should be noted on the plots. Then the user subjectively decides whether there are any inconsistencies in the record for any of the stations and inputs appropriate adjustment factors, as needed, to correct the data. Consistency adjustments can be applied on a seasonal or annual basis. Seasonal corrections are typically used when snow predominates during one season and rain during the rest of the year since snow catch is typically affected more by exposure or equipment changes.

Two of the precipitation records for stations within or in close proximity to the Row River watershed showed inconsistencies in their records. These were the hourly data for the Dorena Dam station (NCDC coop station # 35-2374) and the hourly data for the Disston 1 NE Laying Creek station (NCDC # 35-2345). Table 2 gives the station history information for these 2 stations based on B-44 forms (earlier version was form 531-1) filed by the CPM's. For the Dorena Dam station there was both a recording and non-recording gage for essentially the entire

Station	Effective date	Elev. (feet)	Change
Dorena Dam	July 1963	757.	Minor relocation of equipment in fenced area that was enlarged
	11/7/66	820.	Station moved 0.4 mi. south
	8/21/72	820.	Station moved 110 yds. East
	5/1/79	820.	Fisher Porter gage replaced weighing recording gage – B-44 indicated that FP was located 0.5 mi. NNE from current weather site adj. to south end of spillway at 870 ft. – subsequent documents make no mention of FP being at a different location than the other equipment.
	5/22/85	820.	Equipment moved 190 ft. south
	12/29/92	820.	Equipment moved 300 ft. northwest
	12/1/98	820.	Equipment moved 700 ft. northwest
Disston 1 NE Laying Creek	June 1960	1218.	Equipment moved 270 ft. east by observer (exact date unknown-old elev. was 1212 ft.)
	4/26/76	1218.	Fisher Porter gage replaced weighing recording gage

Table 2. Documented changes for Dorena Dam and Disston 1 NE Laying Creek.

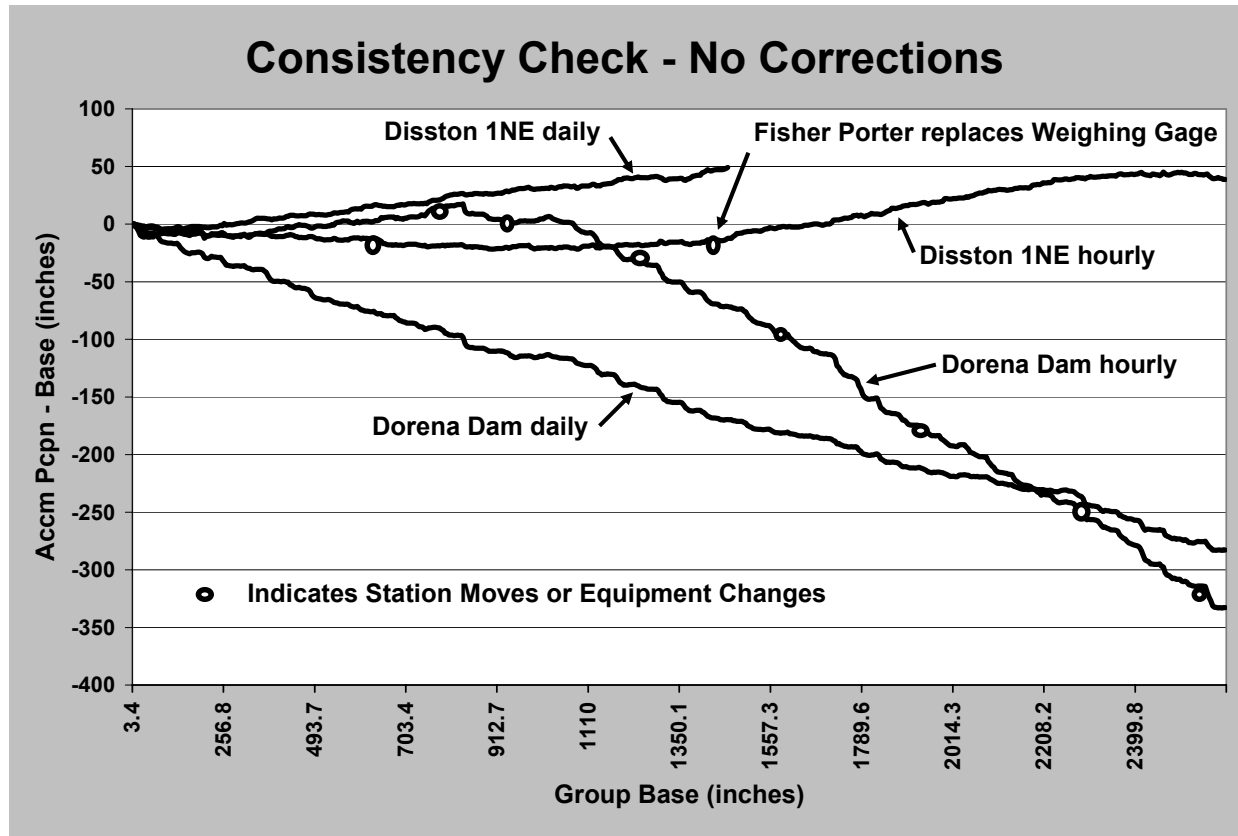


Figure 2. Double mass plots for Dorena Dam and Disston 1 NE Laying Creek (WY 1950-1999).

period of record. For the Disston 1 NE Laying Creek station the daily record was discontinued on January 12, 1976 shortly before the weighing gage was replaced by a Fisher Porter type recording gage. Figure 2 shows the double mass plots for all the records at these 2 sites. The times when station moves or equipment changes occurred are marked on the lines for the hourly stations. The figure shows that the double mass plots for the non-recording (daily) gages are consistent over their period of record. The hourly data for Disston 1 NE Laying Creek shows a change in slope at the time when the weighing gage was replaced by a Fisher Porter gage. Although at most sites a change from a weighing to a Fisher Porter gage doesn't cause an inconsistency in the record, it has been observed at some locations. The change is most likely due to a problem in how one of the gages was installed or calibrated. In this case the subsequent Fisher Porter record has a more similar slope to the record from the daily gage prior to 1976 suggesting that the problem was more likely associated with the weighing gage, however, it should be noted that adjacent recording and non-recording gages seldom catch the same amount though their slopes on a double mass plot are generally fairly similar. When the double mass plots were generated on a seasonal basis using the winter and summer seasons selected for this region by the NWRFC (winter is defined as November through April), the computed consistency correction was the essentially the same for both seasons. Thus, it was not justified to apply a correction on a seasonal basis which is reasonable since snow seldom occurs at these elevations. A correction of 1.06 was applied to all the data from the beginning of the record through April of 1976 in order to make this period consistent with the later data.

For the hourly record at the Dorena Dam site there is clearly an inconsistency in the record as noted by the large change in slope shown in Figure 2. This slope change appears to occur around an accumulated group base value of 1050 inches though it is difficult to determine exactly where the change occurs due to the amount of wobble up to that time and the scale of the plot. In order to get a better idea of when the change occurred, Figure 3 shows a more detailed version of the double mass plot for the years 1962 through 1972. The large decreases in December 1964 (X axis≈155) and December 1965 and January 1966 (X axis≈205) are due to the monthly totals being estimated and should be ignored. From Figure 3 it appears that the slope change began around the end of 1968 or early in 1969 (X axis≈340-350). There were no documented station changes at this time (see Table 2). The documented moves prior to and after that period show no slope changes on the double mass plots. Thus, while the plots clearly show that something happened, there is no documentation of a change taking place. However, even though the cause is unknown, the change in the data record is so large that it can't be ignored. There was an extended period of missing data starting in January 1969 and extending into February. Without any other information, the assumption was made that the inconsistency occurred during this outage. As with Disston, corrections computed on a seasonal basis were very similar, thus an annual correction was applied (note: it appears from the end of Figure 3 that there may be a

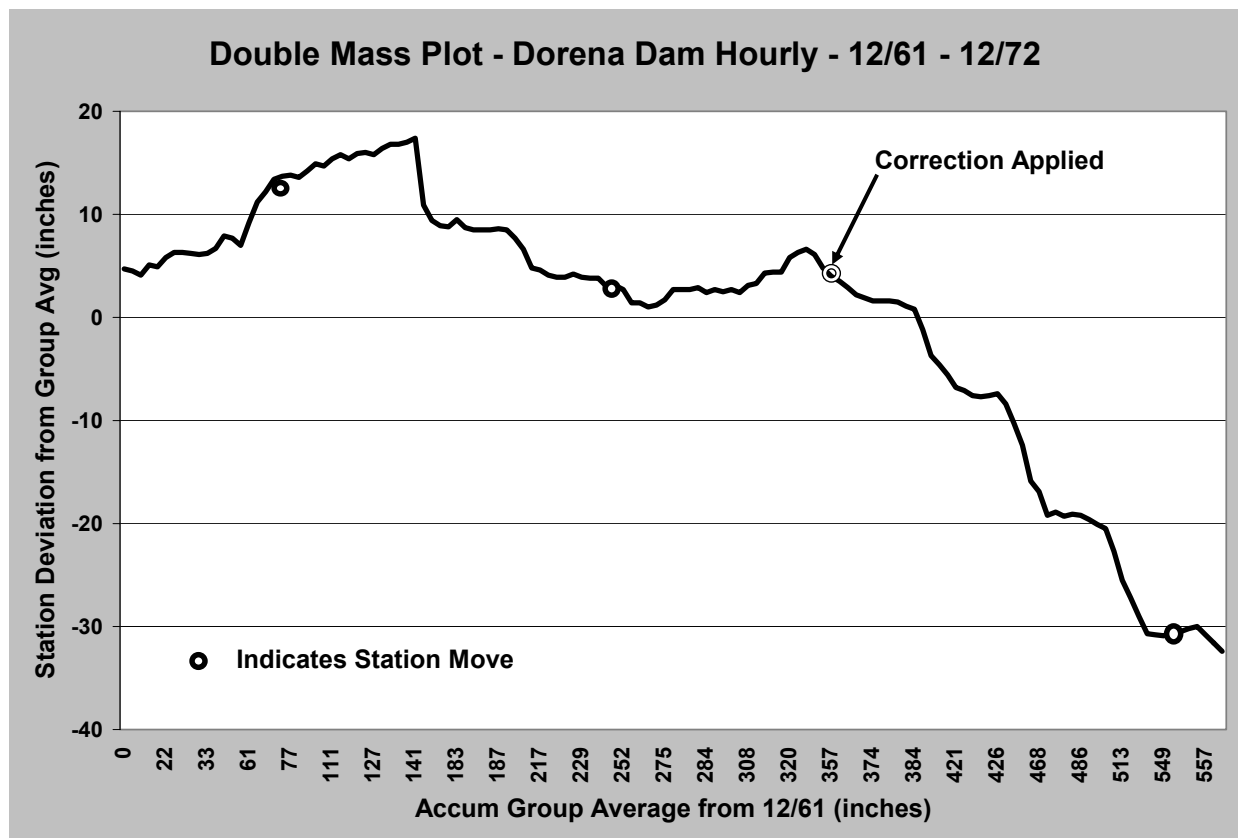


Figure 3. Double mass plot for Dorena Dam hourly record for 1962-1972.

seasonal pattern to the double mass plot, however, when looking at plots for the entire period of record on a seasonal basis, the slopes for both seasons are essentially the same). A correction of 0.76 was applied to the hourly data from Dorena Dam starting in February 1950 when the record began through January 1969 in order to make the early part of the record reasonably consistent with the later data. The effect of the corrections for both stations is shown in Figure 4. One thing that is odd about the Dorena Dam record that should be noted is that the slope of the hourly record, neither before nor after the consistency correction, is similar to that of the daily gage. This is unusual. There is no evidence in the station history documentation of why the slopes are so different or why the catch changed so dramatically.

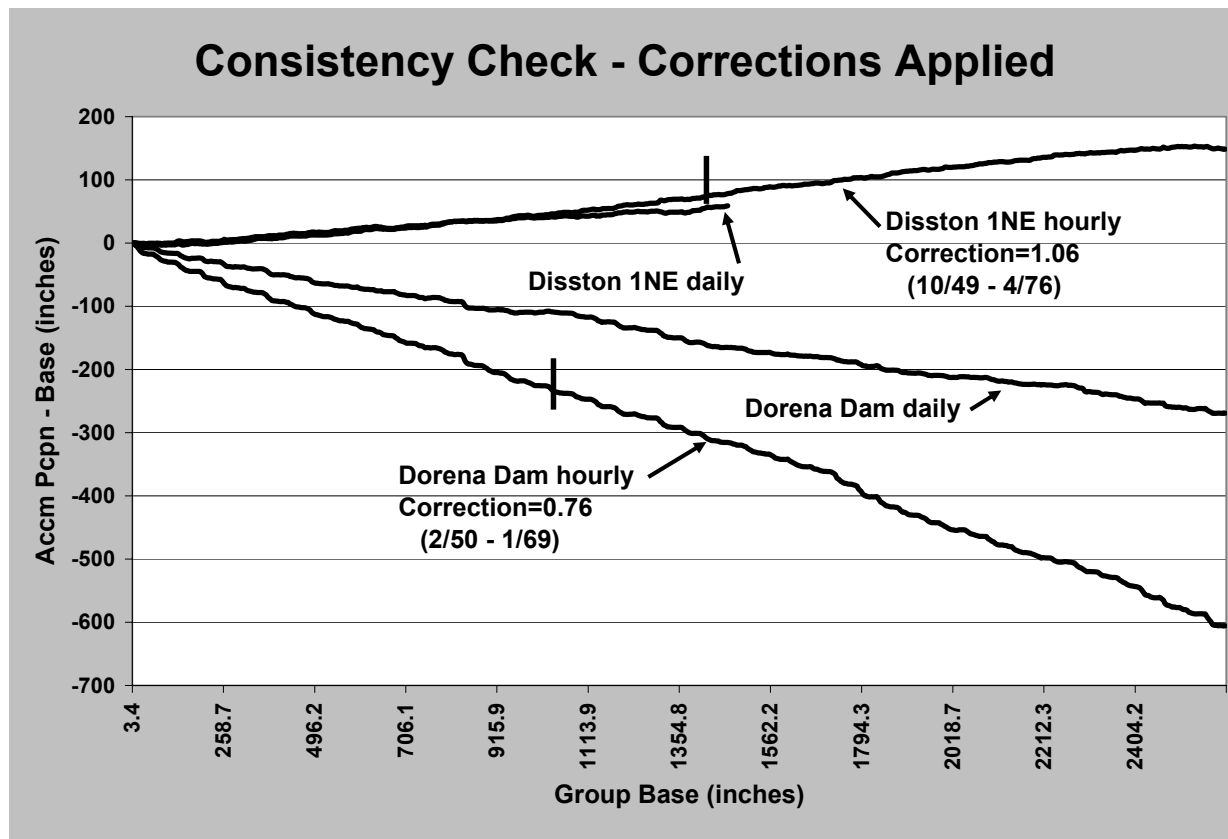


Figure 4. Double Mass plots for Dorena Dam and Disston 1 NE after Corrections Applied.

Mean Areal Precipitation

Mean Areal Precipitation (MAP) time series were produced for both watersheds [i.e. the Row River above Pitcher Creek (referred to as ROWO3 for the remainder of this report) and the Dorena Dam inflow (referred to as DORO3i)]. Prior to generating any time series, decisions had to be made regarding subdividing of the watersheds into elevation zones and the appropriate long-term average precipitation to use. The watersheds were divided into 2 elevation zones with the division at 3000 feet. This elevation was selected based on snow depth and water equivalent data at various elevations. The upper elevation zone exhibits a snow cover that persists for much

of the winter during most years. The lower zone only has snow for brief periods during some years.

The initial estimates of the long-term average precipitation over the watersheds were based on the PRISM isohyetal analysis for Oregon (PRISM is based on the 1961-1990 period). This estimate was revised downward based on comparisons with station measurements and a water balance analysis for the ROWO3 watershed. Annual station weights were used in the MAP computations, rather than seasonal weights, since the ratio of high to low elevation precipitation didn't vary significantly from one time of the year to another. Table 3 gives the basic information for each elevation zone for the two watersheds.

Watershed	Lower Elevation Zone			Upper Elevation Zone		
	Fraction %	Mean Elev.	Mean Pcpn	Fraction %	Mean Elev.	Mean Pcpn
ROWO3	61	2200 ft.	55 in.	39	3800 ft.	64.5 in.
DORO3i	68	2000 ft.	54.7 in.	32	3800 ft.	64.5 in.

Table 3. Elevation Zone Information

The procedure used to produce MAP time series in mountainous areas starts by assigning relative weights to each station. Relative weights sum to 1.0 and are subjectively based on the location and elevation of the station relative to the area and on other factors such as prevailing storm type and direction. The relative weights are then adjusted by a factor computed by taking the long-term average precipitation for the area and dividing it by the summation of the relative weight multiplied by the long-term average precipitation for each station. Multiplying the relative weights by this factor gives the actual weights used in the MAP computations and insures that the time series will produce the proper long-term areal average.

Various MAP time series were generated for the two watersheds for use in this study. These were:

1. Case 1: ROWO3 – time series used for model calibration. Consistency corrections applied for both Dorena Dam and Disston 1 NE. For the lower elevation zone weight was assigned to the Disston 1 NE hourly station and the Dorena Dam daily station (this is how the MAP time series would generally be produced – consistency corrections are applied and daily stations are typically assigned the weight when both hourly and daily gages exist at a given site unless the hourly record is much longer than the daily record).
2. Case 2: DORO3i – used to verify that the ROWO3 calibration was valid for the Dorena Dam inflow. Consistency corrections and weights applied as for ROWO3.
3. Case 3: DORO3i – used to determine the effect of consistency corrections on simulation results. For the lower zone weight was assigned to the stations that had inconsistencies, i.e. Dorena Dam hourly and Disston 1 NE hourly. Four variations of MAP time series using these stations were generated:
 - a. Consistency corrections applied to both hourly stations,
 - b. No correction applied to either station,
 - c. Dorena Dam hourly corrected, but not Disston 1 NE hourly, and
 - d. Disston 1 NE hourly corrected, but not Dorena Dam hourly.

For these cases Table 4 gives the stations used and their relative and actual weights for each elevation zone.

Elevation Zone	Case	Stations	Relative Weight	Actual Weight
Upper	All	Holland Meadows SNOTEL	0.6	0.545
		Upper Steamboat Creek	0.4	0.364
Lower	1	Disston 1 NE hourly	0.75	0.781
		Dorena Dam daily	0.25	0.260
Lower	2	Disston 1 NE hourly	0.6	0.636
		Dorena Dam daily	0.4	0.424
Lower	3	Disston 1 NE hourly	0.6	0.678
		Dorena Dam hourly	0.4	0.452

Table 4. Stations and weights used to compute MAP time series.

It should be noted that for DORO3i station weights were assigned so that the same long-term areal average precipitation would occur in all cases for the period after the consistency corrections were applied (i.e. water years 1977-1999). This was done so that the calibrated model parameters (see next section) would not have to be adjusted slightly from one case to another. The long-term average precipitation for the entire 50 year period varies somewhat from one set of MAPs to another for the lower elevation zone depending on which consistency corrections are being applied prior to water year 1977 (values for the upper elevation zone are the same in all cases since the same stations are used and there are no consistency corrections applied to these stations).

Model Calibration

The NWSRFS SNOW-17 snow accumulation and ablation model and SAC-SMA soil moisture accounting models were calibrated to the ROWO3 watershed using water years 1988 through 1999. This period had the most data and involved no consistency corrections. Potential Evaporation (PE) estimates were developed based on low elevation pan data from long records at Lookout Point and Fern Ridge Dams and from meteorological calculations using data from the Salem WB Airport site. High elevation PE was estimated by taking the low elevation estimate and adjusting it by the ratio of pan evaporation at the Odell Lake Land Pan site to the Lookout Point Dam site for the period when both pans were in operation. PE values for the two elevation zones were then derived by linear interpolated between the low and high elevation estimates. The seasonal PE adjustment curve was based on the fact that the watershed is primarily covered by conifers and has a relatively mild climate, thus the monthly adjustments should remain fairly high all year. Some adjustments were made to the initial curve during calibration. The final curve had values of 1.0 during the winter and early spring with the adjustment rising to a maximum of 1.3 in July. Mean areal temperature (MAT) time series were generated for each zone utilizing 13 max/min stations spanning the elevation range of the watershed. Temperature consistency corrections were applied to several of the low elevation stations, but have little effect on the results since most of the snow occurs in the upper elevation zone.

The SNOW-17 model was calibrated using both streamflow and snow data. MAT values were altered in some cases to correct the form of precipitation. These MAT changes were based on observed changes in snow depth and the hydrograph response. Since the amount of snowmelt runoff is relatively small for this watershed and melt is spread out over a fairly long period due to the elevation range and the heavy forest cover, more emphasis was placed on comparing simulated snow depth and water equivalent to measurements at several of the sites, than on streamflow, when making adjustments to model parameters.

The Sacramento model was calibrated following procedures and recommendations given in the Calibration Manual. The water year 1977 through 1987 period was used to verify the calibration. This period was also not affected by any of the consistency corrections. As seen in Table 5 the statistics for this period were generally similar to those for the calibration period for ROWO3.

Except for adjustments to the area-elevation curve and the unit hydrograph due to a different drainage area, the exact same parameters were used for the DORO3i simulations as were used for the ROWO3 watershed. Comparisons were made in order to verify that the DORO3i simulations were compatible with the ROWO3 simulation and thus could be used to determine the effect of the consistency corrections on model output. The results of these comparisons are also shown in Table 5. As can be seen the statistics for DORO3i for both cases are basically the same as the results for ROWO3.

Site	Period (WY)	All Flows				High Flows	
		Bias %	Daily RMS/Q	Monthly RMS/ro	Correlation Coef.	Bias %	RMS/Q
ROWO3	88-99	0.03	0.59	0.29	0.933	-8.6	0.28
ROWO3	77-87	1.5	0.63	0.27	0.929	2.1	0.29
DORO3i Case 2	88-99	0.2	0.59	0.26	0.933	-6.3	0.28
DORO3i Case 2	77-87	1.2	0.63	0.25	0.932	4.3	0.30
DORO3i Case 3	88-99	0.15	0.61	0.26	0.927	-7.1	0.28
DORO3i Case 3	77-87	0.16	0.64	0.27	0.929	3.3	0.31

Table 5. Mean daily flow statistics for the calibration and verification periods.

Results and Discussion

Inconsistencies in precipitation data will potentially have the greatest effect on runoff computations when the stations with the inconsistencies have a large weight in the MAP computations. In this case the maximum weight for the two stations with inconsistencies occurs for the DORO3i watershed, thus this drainage was used to test the impact of consistency corrections on simulation results. The gages with the inconsistencies, i.e. the hourly gages, were given the weight in the MAP computations for the lower elevation zone (i.e. case 3). As

mentioned in the Mean Areal Precipitation section, 4 scenarios were run to assess the effect of making the corrections. Figure 5 shows the accumulated errors in simulated runoff that result from each of these scenarios.

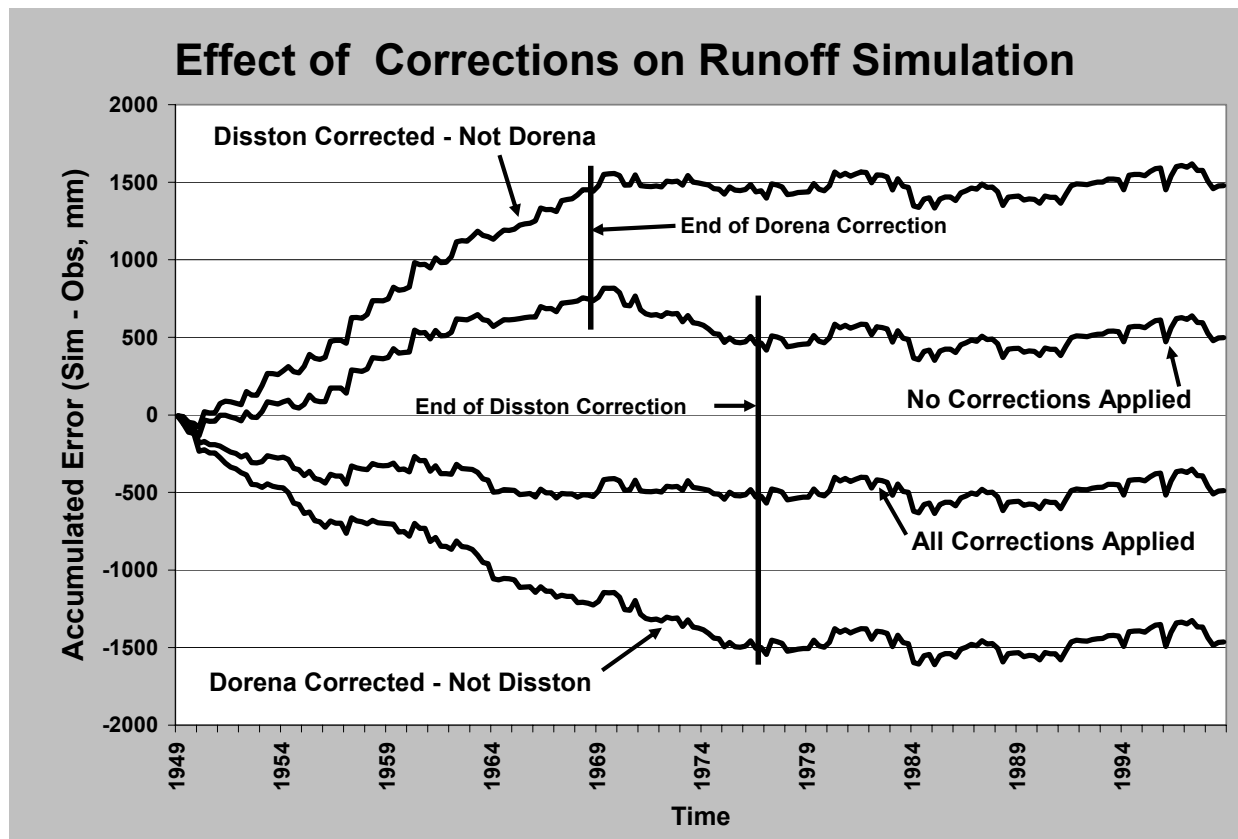


Figure 5. Accumulated errors in simulated runoff for various MAP scenarios.

From Figure 5 the following comments appear valid for the various MAP scenarios:

1. All Corrections Applied – The accumulated error is quite stable over most of the 50 year period. The exception is during the first 5 or 6 years when there is an under simulation of runoff. The reason for this is uncertain but could be caused by the fact that neither of the stations used to compute the upper elevation zone MAP nor most of the stations used to estimate missing data at these sites existed prior to around 1955 or 1956. The data for the upper elevation zone stations for this early period were estimated almost exclusively from stations at much lower elevations some distance away.
2. No Corrections Applied – In this case the inconsistencies in the Dorena Dam and Disston 1 NE hourly records somewhat offset each other. Disston 1 NE has a much smaller correction than Dorena Dam but in the opposite direction (1.06 compared to 0.76), however, Disston 1 NE has a greater weight in computing MAP for the lower elevation zone than Dorena Dam (0.68 compared to 0.45). From near the beginning of the period of record until about 1969 the greater catch in the Dorena Dam gage (relative to the period after that date) has the largest effect, causing runoff to be over computed. From

about 1969 until 1976 the lower catch in the Disston 1 NE gage (relative to the catch after that date) causes an under simulation of runoff. After the last inconsistency in the precipitation records the error pattern is quite stable

3. Disston 1 NE Corrected, but Not Dorena Dam – In this case the only precipitation inconsistency is the greater catch by the Dorena Dam gage until early 1969. This produces a considerable over simulation of runoff for that period.
4. Dorena Dam Corrected, but Not Disston 1 NE – In this case the only inconsistency is the lower catch in the Disston 1 NE hourly gage through 1976 which ends up producing a clear under simulation of runoff during that period.

Conclusions

Based on the simulation results presented in this study the following conclusions are offered regarding the effect of correcting or not correcting precipitation for inconsistencies on the calibration and operational use of conceptual hydrologic models for river forecasting:

1. The simulation results are more stable over time when the precipitation data are corrected for inconsistencies. While there is a certain amount of noise in conceptual model simulation results caused by the input used and the simplified structure of the models, there is little deviation in the overall trend of the accumulated errors when the precipitation data are consistent. The variability in forecast results could be greater or less than that seen in historical simulations depending on the data networks, but the overall trend should be the same as long as the operational input data are unbiased as compared to that used for calibration.
2. Large inconsistencies in the precipitation record for a station have a very significant effect on simulation results when the station has a sizeable weight in the MAP computations for a watershed. The result will be an inconsistent pattern in the simulation of runoff over time. Model parameters determined by calibrating on different portions of the period of record will vary significantly more if the data are not adjusted for inconsistencies than if consistency corrections are properly applied. The main parameters that will likely differ from one portion of the record to another are those that control the water balance and the volume of runoff (e.g. SCF in the SNOW-17 model and tension and free water storage capacities and the ET-Demand curve for SAC-SMA).
3. It is best to check all the stations for inconsistencies and make corrections as justified. Since the historical precipitation analyses are done on a regional basis at the NWS River Forecast Centers (RFCs) and involve many stations and watersheds, any given station will be weighted by different amounts for different watersheds. Thus, even though small corrections for minimally weighted stations or offsetting corrections would have a minor effect on results for a given drainage, these inconsistencies could be significant for another watershed. It would be quite difficult to determine which station's consistency corrections will be insignificant for all watersheds in the regions.

4. Inconsistencies in precipitation data that make it difficult to determine model parameter values will also reduce the chances that the MAP time series can be used to properly reflect the statistical distribution of what may happen in the future as part of an ensemble approach to extended streamflow predictions. Large inconsistencies for a station that has significant weight for an MAP area will especially warp the true distribution of historical precipitation scenarios.

Summary and Observations

In summary it seems clear from this study, based on using real data, that inconsistencies in precipitation records for climatological stations, besides producing an inconsistent pattern of computed runoff, can significantly affect the chances of determining proper parameter values for conceptual models during calibration and will decrease the utility of using the MAP time series generated from the data in an ensemble approach for making extended streamflow predictions. It is recommended that historical precipitation data be carefully checked for inconsistencies and corrected following suggested guidelines before the data are used to produce model inputs.

There is also a question regarding the overcorrecting of precipitation data that is not addressed directly in this study. In the extreme case the data would be corrected so that they plot as a nearly perfect straight line on a double mass plot. It is clear that there is a considerable amount of natural variability in the spatial and temporal distribution of precipitation such that even totally consistent data will never plot as a perfectly straight line. However, it is also logical that when a station is moved or the equipment altered, there is a chance that the subsequent record will not be consistent with the previous data. It requires a careful analysis and good judgment to discover true inconsistencies in the data, especially in regard to the NCDC climatological network where station history documentation is often incomplete. If precipitation data are overly corrected, it is not clear whether this will have a significant effect on determining model parameters. This is because parameter values are generally based on normal conditions and not extremes. Certainly it seems like overly correcting the data will affect the distribution of historical precipitation scenarios and thus affect extended predictions.

It also should be recognized that inconsistencies don't just occur in the historical record. An operational station can also be moved or have its equipment changed at some point in the future. This needs to be monitored. Operational data should periodically be checked for consistency and corrections applied when justified. Typically the historical stations are corrected to be compatible with their current configuration, thus if they are available operationally there is no need to initially apply any correction. In some cases, especially in mountainous areas, stations are corrected during the historical analysis to be consistent with an earlier location which is thought to be more representative of the actual spatial precipitation pattern. The recommended procedure for computing station weights in mountainous areas insures that the same long-term areal average will be produced no matter what is the long-term station average. In this study, for example, it didn't matter whether the weight for Dorena Dam was assigned to the daily or hourly gage even though their catch was quite different, as long as the data were consistent. Thus, it is recommended that historical stations always be corrected to be consistent with their current location and equipment if their data are also available operationally.

Operationally a bias can also occur in the precipitation input for the models when stations are used that were not part of the historical analysis. In order to generate precipitation inputs that are consistent with the data that were used for model calibration, the long-term average for the historical period of record should be known for each operational station. This is independent of whether a mountainous or non-mountainous area procedure is used to generate the MAP time series. For a mountainous area the long-term average is needed to properly compute station weights. For a non-mountainous area the long-term average is needed to confirm that the station is consistent with the assumptions behind treating the region as non-mountainous. If the operational precipitation estimates are biased as compared to those used for calibration, the same effects will result as were evident in this study, i.e. an over or under estimation of runoff.

This study didn't include the effect of inconsistencies in temperature data on the simulation of snowmelt runoff since snow has a relatively minor effect in the watersheds used and the only inconsistencies noted in the temperature data were at low elevation sites. Inconsistencies in temperature records will affect the determination of the form of precipitation and most importantly the timing of snowmelt. The timing of snowmelt in the SNOW-17 model is very sensitive to temperature. A temperature bias of a few degrees can cause a pronounced shift in the timing of the snow ablation. Thus, all of the statements in this report concerning the need to correct precipitation data for inconsistencies and to make sure that operational estimates are consistent with the data used for calibration should be applicable to temperature data.

Acknowledgements

Special thanks go to Kevin Berghoff of the NWRFC for looking at a number of locations to find an appropriate dataset for this study and then for providing the data and other information needed to do the analysis.